RECOMMENDATIONS FOR 15% ABOVE-CODE ENERGY EFFICIENCY MEASURES ON IMPLEMENTING HOUSTON AMENDMENTS TO SINGLE-FAMILY RESIDENTIAL BUILDINGS IN HOUSTON TEXAS

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ABSTRACT

This paper presents information about the energy saving potential for single-family residential buildings in Houston, Texas that are designed to be 15% above code. The energy efficient measures discussed in this paper were proposed by the building officials of the City of Houston. Along with the options proposed by the officials, additional measures were selected from the 15% above code energy analysis previously conducted by the Energy Systems Laboratory for residential houses across the State of Texas. In this analysis a total of thirty-one measures were analyzed based on the energy savings above a base-case, code-compliant house. These measures were categorized into five groups: Renewable Energy options, Heating Ventilation and Air Conditioning (HVAC), Fenestration, Envelope, Lighting and Domestic Hot Water (DHW) options. The analysis was performed using an hourly simulation of an International Energy Conservation Code (IECC)-compliant, single family residence in Houston, Texas. Four sets of simulations were performed based on the choice of heating fuel type and thermostat setback.

Individual measures were then categorized into four groups: 2 to 5%, 5 to 10%, and 10 to 15% and above 15% energy savings. Ten groups were then simulated by combining individual measures from the four categories whose combined savings are more than 15% above the base case. The cost of the implementation of the individual, as well as group measures was also calculated along with simple payback period. Photovoltaic options presented the maximum savings in the approximate range of 15-40% for all base-case houses depending on the size of the installed array. The solar thermal option for domestic water heating showed a savings above 15-20% for all the base-case houses.

INTRODUCTION

This paper presents the results of an analysis requested by the City of Houston building officials. In this paper the results of the measures that the city officials have proposed, along with additional measures which were selected from the 15% above code energy analysis previously conducted by the Energy Systems Laboratory for single-family homes across the State of Texas (Malhotra 2007). In this analysis a single-family residence complying with the 2000 International Energy Conservation Code, as modified by the 2001 Supplement[1] (ICC 1999; 2001), is taken up as the base case.

Four sets of simulations were used in this analysis, which are based on the choice of heating fuel type and thermostat setback,including: a) natural gas (i.e., gas-fired furnace for space heating, and gas water heater for domestic water heating) with thermostat setback, b) electricity (i.e., heat pump for space heating, and electric water heater for domestic water heating) with thermostat setback, c) natural gas (i.e., gas-fired furnace for space heating, and gas water heater for domestic water heating) without thermostat setback, and d) electricity (i.e., heat pump for space heating, and electric water heater for domestic water heating) without thermostat setback.[2].

BASE-CASE BUILDING DESCRIPTION

The base-case house assumptions in this analysis are based on the "standard design" as defined in Chapter 4 of the 2001 IECC and certain assumptions that are described in the paragraphs following. Four sets of simulations were used which are based on the choice

[1] In the remainder of this paper, this will be denoted as the 2001 IECC.

[2] The simulation was conducted using version 2.50.08 of the laboratory's code compliant simulation and a TMY2 weather file for the City of Houston, Texas

of heating fuel type and thermostat setback. Table 1 summarizes the base-case building characteristics used in the DOE-2 simulation model.

Building Envelope, Space and Interior / Exterior Lighting Characteristics

The base-case building is a 2,325 sq. ft., square-shaped, single story; single-family, detached house facing South, with a floor-to-ceiling height of 8 feet[3]. The house has a vented attic with a roof pitched at 23 degrees, which contains the HVAC systems and ductwork. The house has fascia brick exterior and asphalt shingle roofing. The wall construction is a light-weight wood frame with 2 × 4 studs spaced at 16” on center with a slab-on-grade-floor. The wall insulation is R-13[4] and ceiling insulation is R-30[5], as recommended by the 2001 IECC. The building has wall and roof absorptance of 0.75. The window area is 18% of the total conditioned floor area[6]. As described in Chapter 4 of the IECC 2001, the windows have no exterior shading, and the window glazing has a U-value of 0.47 Btu/hr-sq.ft.°F[7] and solar heat gain coefficient as 0.4[8]. Two 20 sq. ft. doors of 0.2 Btu/h-sq. ft.-°F U-value[9] were assumed to be located on the north and south exterior walls. The air infiltration rate was 0.47 ACH, which is based on the weather factor specified in ASHRAE Standard 136-1993 (ASHRAE 1993)[10].

The space temperature set points are 68°F for heating,and 78°F for cooling, with a 5°F set-back/ set-up for winter and summer, respectively, for 6 hours per day[11]. The total internal heat gain is assumed to be 0.88 kW[12] (modeled as 0.44 kW for lighting and 0.44 kW for equipment)., No occupants are assumed to be in the simulated house. 100% interior / exterior incandescent fixtures are assumed for the base-case house. No occupancy sensors were installed in the exterior lighting fixtures[13]. Exterior lighting fixtures were assumed to be on from sunset to sunrise

HVAC System Characteristics

The base-case HVAC system includes a central air-conditioning system and heating system. Two options for the heating fuel type were considered:
a) natural gas (i.e., gas-fired furnace for space heating, and gas water heater for domestic water heating), and b) electricity (i.e., heat pump for space heating, and an electric resistance water heater for domestic water heating)[14]. For the electric/gas house, the base-case HVAC system is comprised of a SEER 13 air conditioner and a gas-fired, forced-air furnace with a 0.78 Annual Fuel Utilization Efficiency (AFUE)[15]. For the all-electric house, the base-case HVAC system is comprised of a SEER 13 air conditioner with a heat pump with a 7.7 Heating Season Performance Factor (HSPF). For both types of houses, the capacity of the cooling system is 55,800 Btu/hr, which assumes 500 sq. ft. per ton. The capacity of the heating system is 44,997 which is Btu/hr, based on the information provided by the Houston officials.

Air Distribution System Characteristics

The base-case air distribution system, which includes the HVAC unit and the ducts, is located in the unconditioned, vented attic. The attic was assumed to have an air infiltration rate of 15 ACH[16]. The insulation for the supply and return ducts was R-8 and R-4, respectively[17]. A 20% supply duct leakage and a 10% return duct leakage was assumed for the base-case house[18].

Domestic Hot Water System Characteristics

For the electric/gas house, the base-case domestic hot water (DHW) system is a 40-gallon[19], storage type, natural gas water heater with a standing pilot

3 The overall characteristics of the house are from the National Association of Home Builders (NAHB 2003)
4 From Table 402.1.1(1) of the 2001IECC.
5 From Table 502.2.4(6) of the 2001 IECC.
6 This amounts to 418.5 sq. ft. window area and 27% window-to-wall area ratio for the base case building size and configuration.
7 From Table 402.1.1(2) of the 2001 IECC.
8 From Section 402.1.3.1.4 of the 2001 IECC.
9 This is specified in Section 402.1.3.4.3, p.64 of the 2001 IECC.
10 This requirement can be found in Section 402.1.3.10, p.65of ASHRAE Standard 136-1993.
11 As defined by Table 402.1.3.5, p.64, of the 2001 IECC.
12 FromSection 402.1.3.6, 2001 IECC.
13 These requirements are from the Houston officials for exterior lighting

14 In the remainder of this paper, these houses will be referred to as (a) electric/gas house, and (b) all-electric house, respectively.
15 The efficiency of HVAC system is determined by requirements of the 2006 NAECA 2006.
16 This infiltration rate was chosen to match measured data by Kim (2006).
17 This requirement can be found in Table 503.3.3.3 of the 2001 IECC.
18 This is based on the information provided by the Houston officials.
19 The size of the DHW storage tank was adopted from the minimum water heater capacities for a four bedroom, 2.5 bath, single family living unit (Table 4, p.49.9, ASHRAE 2003)

light that consumes 500 Btu/hr[20], with a calculated energy factor (EF) of 0.54[21]. For the all-electric house, the base-case DHW system is a 50-gallon, storage type, electric water heater. The energy factor (EF) of the system all electric is 0.86[17]. The daily hot water use was calculated as 70 gallons/day[22], which assumes that the house has four bedrooms. The hot water supply temperature is 120°F[23].

The method to simulate the hourly energy use of the DHW in the DOE-2.1e program, uses the energy factor, based on the Building America House Performance Analysis Procedures (NREL 2001) that assumes a constant hourly DHW use, which eliminates the inefficiencies due to the part-loads.

UTILITY COST ANALYSIS

The utility cost analysis for the different measures was carried out using three different utility cost rates. The cost of energy for each case is 30% more than the previous case. The intention of using the three cost rates is to calculate several possible paybacks in the event of an increase in fuel prices over a period of time. For the first case, the cost of electricity and natural gas are taken as $0.15/kWh for electricity and $1.00/CCF for natural gas. For the second case, the cost of electricity and natural gas are taken as $0.20/kWh for electricity and $1.50/CCF for natural gas. For the third case, they are $0.25/kWh for electricity and $2.00/CCF for natural gas respectively.

SUMMARY OF INDIVIDUAL ENERGY EFFICIENCY MEASURES

For the analysis, 31 individual measures were considered, some of which were proposed by the City of Houston officials. Others were taken from the Laboratory's previously published 15% above code analysis report (Malhotra 2007). These include measures for the renewable power options, options related to HVAC system & air distribution system, fenestration, building envelope, and options for the domestic hot water (DHW) system. These measures were simulated by modifying the selected parameters used for the Laboratory's code-compliant simulation which is based on the DOE-2 simulation model. Table 2 shows the Energy Efficiency Measures (EEMs) which were simulated for the electric/gas and all-electric base-case house. The measures for the simulation without the with thermostat setback are same as those with thermostat setback with the exception of the setback.

Renewable Power Options

The test-case house was assumed to be grid-connected with a 6 kW, 4 kW or 2 kW PV array of solar cells (16% efficiency). The analysis of long-term performance was performed using PV F-CHART (Klein and Beckman 1983) for weather conditions in Houston based on TMY2 weather data. Details are provided in the report by Liu et al. (2008). The cost of installation varied with the type of system—for a 6 kW system the cost is around $41,000 and for 4 kW and 2 kW systems the costs are $29,000 and $17,000 respectively.

HVAC Options

Six measures were elavluated to improve the HVAC performance including a)Increased Square Footage per Ton b) Changing the Supply Airflow, c) Decreased Duct Static Pressure, d) Deceased Duct Leakag, e) Mechanical Systems within Conditioned Spaces and,f) Improved SEER and Furnace Efficiency
Increased Square Footage per Ton: Manual-J calculations were used for efficient system sizing as reported by building officials and is around 650 sqft/ton.

Changing the Supply Airflow: Two cases were simulated. The first case used a decreased air flow and the second case is with increased air flow. In the first test case a reduced value of 250 cfm/ton was considered. In the second test case an increased value of 450 cfm/ton was considered to check the sensitivity of the model.

Decreased Duct Static Pressure: For the test case the static pressure for HVAC duct system was set at 0.5" WC[24] certified by a third party. The cost for implementing the change in static pressure was assumed to be $250. The cost information was obtained from estimated costs proposed by the City of Houston officials. Details are provided in the report by Liu et al. (2008).

[20] This value is consistent with information provided by DHW manufacturers.
[21] The EF of the DHW system was calculated from the minimum performance requirement using Table 504.2of the 2001 IECC.
[22] This is specified in Section 402.1.3.7of the 2001 IECC.
[23] This is specified in Section 402.1.3.7,of the 2001 IECC.
[24] This is based on the information provided by the Houston officials.

Deceased Duct Leakage: As requested by the City of Houston, the energy efficiency measure were be reset at 6.7% for supply and 3.3% for return ducts. The cost of implantation for decreasing the duct leakages was assumed to be between $200 and $450.

Mechanical Systems Within Conditioned Spaces: This measure analyzed the energy savings that would occur if the entire HVAC system, including the supply and return ductwork, was moved from the attic location in the base-case house to a location within the thermal envelope of the conditioned space. Relocating the HVAC System and ductwork in the conditioned space increased the cost by $1,000 to $7,000.

Improved SEER and Furnace Efficiency: For this measure , the SEER 13 air conditioner in the base-case house was replaced with a similarly sized SEER 15 air conditioner. The gas-fired furnace in the electric / gas base-case house (0.78 AFUE) was replaced with a similarly sized condensing furnace with an AFUE of 0.93. Replacing a SEER 13 air conditioner with a SEER 15 air conditioner increased the cost by $900 to $2,500. Replacing a 0.78 AFUE furnace with a 0.93 AFUE furnace increased the cost by $600 to $1,500.

Fenestration Options

Several options were analyzed to improve the window performance including a) Decreased SHGC and U-value, and b) Window Shading and Redistribution,

Decreased SHGC and U-value: In one measure an SHGC of 0.3 was used. In another measure, a U-Factor of 0.35 Btu/h-sq. ft.-°F and an SHGC of 0.30 was simulated. The cost of improving the SHGC and U-value of the fenestration system was assumed to be between $900 and $1,100.

Window Shading and Redistribution: In this measure window shading was simulated by modeling 4 ft. roof overhangs on all four sides. The gross window area, orientation, and other characteristics were kept the same as the base-case house, which did not have overhangs. The depth of overhangs was determined from the recommendations by Malhotra et al. (2006). However, the overhang depth on all sides was not optimized for construction cost. Adding a 4 ft. roof overhang increased the cost by $3,100 to $3,500.

In another measure, the house was simulated with the windows distributed 49% on the south, 27% on the north, and 16% each on the east and west orientations. A 2 ft. roof overhang was also included on all four sides. Adding 4-foot roof overhangs would increase the cost by $3,100 to $3,500. This window redistribution in a new construction was assumed to have no increased cost.

Envelope Options

To improve the opaque envelope performance three measures were considered including a) Radiant Barrier,, b) Decreased Infiltration c) Low slope roof with increased reflectance.

Radiant Barrier: As requested by the City of Houston officials a radiant barrier was simulated in the attic in a position directly beneath the sloped roof.

Decreased Infiltration: Two test cases for changed infiltration were simulated—one with the a decreased air change of 0.35 ACH and one with an increased air change of 0.65 ACH as requested by the City of Houston officials. The cost of decreasing infiltration was assumed to be between $350-$1,500.

Low Slope Roof with Increased Reflectance: in this measure the building was simulated with the roof having a slope of (9°) with the decreased roof absorptance of 0.3.

Lighting Options

Two measures were analyzed to provide efficient lighting including a) Energy Star Indoor Lamps and b) Exterior Lighting Options.

Energy Star Indoor Lamps: Variations of high efficiency lamps were simulated. In the first case, 25% of the residence was assumed to have fluorescent lamps. Assuming that a fluorescent lamp uses 75% less energy than an incandescent lamp—the resulting internal heat gain from the use of 25% fluorescent lamps was 0.36 kW. In the second case, 50% fluorescent lamps were used,with the resulting internal heat gain from the lights of 0.275kW. The cost of implementing the 25% fluorescent lighting was $100 and the cost of implementing the 25% fluorescent lighting is $500-$800.

Exterior Lighting Options: Incandescent lamps with occupancy sensors, fluorescent lamps, and fluorescent lamps with occupancy sensors were the three measures considered for the simulating efficiency measures for exterior lighting. These measures reduced average daily lights by 1%.

Domestic Hot Water (DHW) System Options

For the DHW system three measures were analyzed including a) use of tankless water heater, b) Removal of the Standing Pilot Light and c) Solar DHW System.

Use of a Tankless Water Heater: For a house with natural gas heating, Energy Factor (EF) for the DHW was changed from 0.54 to 0.745[25] [26]. For an all electric house, this measure was simulated by increasing the DHW energy factor from 0.86 to 0.95. Installing a tankless electric water heater in an electric/gas house increased the cost by by $1,000-$3,500 . While installing a tankless electric water heater in an all-electric house increased the cost by $700 to $1,400.

Removal of the Standing Pilot Light: This measure was only applicable to an electric/gas house. The resultant change in the DHW Energy Factor (EF) from 0.54 to 0.57 was simulated, along with the removal of an hourly energy use equivalent to an average pilot light (i.e., 500 Btu/h). Replacing a gas water heater with a standing pilot light with a water heater with an electronic ignition increased the cost by $200 to $600.

Solar DHW System: For this measure, a solar thermal DHW system, comprised of two 32 sq. ft. of flat plate solar collectors, was analyzed using the F-Chart program (Klein and Beckman 1983). In this analysis, the collector tilt was assumed to be the same as the latitude, and assumed a hot water use of 70 gallons/day, year around. Table 3 lists the characteristics of the solar thermal system for Houston. In this analysis, any supplementary domestic water heating was provided by the base-case water heating system. Also, additional electricity use was added to account for operating the solar thermal pump. Installing a solar DHW system increased the cost by $2,900 to $5,200.

SIMULATION INPUTS AND RESULTS FOR INDIVIDUAL MEASURES

Table 4 lists the parameters used for the Energy Efficient Measures (EEMs) for electric/gas house with a thermostat setback located in Houston (Harris County), Texas. The first row of values in all the tables presents information used in the base-case runs. The remaining rows present information used in the simulation of the individual energy efficiency measures. The shaded cells in each row indicates the change in the values used to simulate the measure.

Table 5 shows the impact of individual EEMs on energy consumption for different end-uses for the electric/gas house with a thermostat setback. Figure 1 shows the annual end use energy use for the sixteen measures. The annual energy use presented in these tables was obtained from the BEPS report of the DOE-2 output file[27]. The tables also include the calculated energy savings of the EEMs compared to the base-case energy consumption which is presented in the last column.

For the electric/gas option with thermostat setbacks, all of the renewable options provided energy savings in the range of 11–35%. In the HVAC options, relocating the mechanical systems into the conditioned space provides a saving of 11%. Decreasing the duct leakage resulted in an energy saving of 7%. When considering options for improving fenestration, decreasing the SHGC and the U-value of all the windows provides an energy savings of 3.9%. Shading and redistribution of windows saves 3.6% of the annual energy consumption. For envelope options decreasing the infiltration saves up to 3.8% of energy consumption. By changing out 25% and 50% of conventional incandescent lighting fixtures with permanent fluorescent fixtures, 3% to 6% of the energy consumption was saved. Using tankless gas water heaters provided an energy saving of 7.0%. Using a solar DHW system provided a savings of 19.8%.

SIMULATION INPUTS AND RESULTS FOR GROUPED MEASURES

Individual measures were grouped into four different categories: 2-5%, 5-10%, 10-15%, above 15% based on their savings above the base case. Individual EEMs with marginal savings above the base case (i.e., below 2% savings above the base case) were not used in group measures combinations. After categorizing, ten group measures were combining the individual measures so that the combined savings of each measure in the group was more than 15% above the base case.

Table 6 shows the categorized individual EEMs for the electric-gas house with a thermostat setback. Table 7 presents a list of the grouped measures for the electric-gas house with thermostat setbacks. Table 8 presents the parameters used in the simulation of the grouped measures. In a similar fashion to Table 4 the first row of values in all the tables show the information used in the base-case

[25] A degradation factor of 8.8% (Davis Energy Group, Inc. 2006) was used when calculating EF for tankless water heaters.

[26] The EF for the tankless water heater is based on a survey of manufacturers and recommendations of the 2008 California Building Energy Efficiency Standards (Davis Energy Group, Inc. 2006).

[27] For the complete analysis refer to Mukhopadhyay et al. (2008).

simulations. The remaining rows present information used in the simulation of the grouped energy efficiency measures. The shaded cells in each row indicate the change in the values of parameters of individual measures selected to simulate the group measure.

Table 9 shows the energy savings for the grouped measures for the base-case house with natural gas heating with thermostat setbacks. The first 3 groups consist of renewable power options; all achieved a savings of more than 20%. Group 4, which consists of mechanical systems within the conditioned space and 50% of fluorescent lamps, provides an energy saving of 17.9%. Group 5, which is a combination of a 2 kW PV Array and Decreased Duct Leakage, provided an energy savings of 19.7% above the base-case. Group 6, which combined a tankless water heater with 50% Fluorescent indoor lamps and decreased infiltration, provided an energy saving of 17.6%. Group 7, which combined decreased duct leakage with 50% Fluorescent indoor lamps and an improved SEER 15air conditioner , provided a savings of 17.4%. Group 8, which is a combination of decreased duct leakage, improved SEER, decreased SHGC & U-value and decreased infiltration, provided the maximum energy savings of 17.5% above the base-case. Group 9, which combined decreased duct leakage, decreased SHGC and U-value, decreased duct static pressure and window shading and redistribution, provided an energy savings of 16% above the base-case. Finally, group 10 combined decreased duct leakage with decreased infiltration and improved SEER and AFUE to provide a savings of 16.3%.

CONCLUSIONS / SUMMARY

This paper presents information about the energy saving potential for residences in Houston, Texas that are designed to be 15% or more above code. A total of thirty-one measures, , were selected. These measures were categorized into five groups: Renewable Energy Options, Heating Ventilation and Air Conditioning (HVAC), Fenestration, Envelope, and Lighting and Domestic Hot Water (DHW) options. The analysis was performed using a simulation of an International Energy Conservation Code (IECC)-compliant, single family residence in Houston, Texas. Four sets of simulations were performed based on the choice of heating fuel type and thermostat setback. Implementation of renewable energy options which included installation of solar DHW system achieved 10-35% energy savings above the base case. Installing mechanical systems in conditioned space provided an 11.2% energy savings above base case. Installing a tankless water heater provided a savings of 7.5% above the base-case.

Individual measures were then categorized into four groups: 2 to 5%, 5 to 10%, and 10 to 15%, and above 15% energy savings. Ten groups were then simulated by combining individual measures from the four categories whose combined savings were more than 15% above the base-case. The cost of the implementation of the individual, as well as group measures, was also calculated along with simple payback period. Photovoltaic options presented the maximum savings in the approximate range of 15-40% for all base-case houses. The solar thermal option for domestic water heating showed savings above 15-20% for all of the base-case houses.

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REFERENCES

ASHRAE. 1993. ANSI/ASHRAE Standard 136-1993 (RA 2006) - A Method of Determining Air Change Rates in Detached Dwellings. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

ASHRAE. 2001. ANSI/ASHRAE Standard 62-2001 Ventilation for Acceptable Indoor Air Quality. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

ASHRAE. 2003. ASHRAE Handbook - HVAC Applications. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Davis Energy Group, Inc. 2006. Measure Information Template: Tankless Gas Water Heaters. 2008 California Building Energy Efficiency Standards.

ICC. 1999. 2000 International Energy Conservation Code. Falls Church, VA: International Code Council, Inc.

ICC. 2001. 2001 Supplement to the International Energy Conservation Code. Falls Church, VA: International Code Council, Inc.

Kim, S. 2006. An Analysis of International Energy Conservation Code (IECC)-Compliant Single-Family Residential Energy Use. Ph.D. Dissertation, College Station, TX: Texas A&M University.

Klein, S.A., W.A. Beckman. 1983. F-Chart Solar Energy System Analysis: DOS Version 5.6. F-Chart Software. Middleton, WI. www.fchart.com.

LBL. 1993. DOE-2 BDL Summary Version 2.1E. LBL Report No. 349346. Berkley, CA: Lawrence Berkeley Laboratory.

Liu, Z., J. Mukhopadhyay, M. Malhotra, S. Kota, J. Haberl, C. Culp, B. Yazdani. 2008. Recommendations for 15% Above-Code Energy Efficiency Measures on Implementing Houston Amendments to Single Family Buildings in Houston Texas, ESL- ESL-TR-08-11-02.

Malhotra, M. and J. Haberl. 2006. An Analysis of Maximum Residential Energy Efficiency in Hot and Humid Climates. Fifteenth Symposium on Improving Building Systems in Hot and Humid Climates. Orlando, FL.

Malhotra, M., J. Mukhopadhyay, B. Liu, J. Haberl, C. Culp, B. Yazdani. 2007. Recommendations for 15% Above-Code Energy Efficiency Measures for Single-Family Residences. 15.5 Symposium on Improving Building Systems in Hot & Humid Climates. San Antonio, TX.

NAECA. 2006. National Appliance Energy Conservation Act.

NAHB. 2003. The Builders Practices Survey Reports. National Association of Home Builders. Upper Marlboro, MD: NAHB Research Center.

NREL. 2001. Building America House Performance Analysis Procedures (NREL/TP-550-27754). Golden, CO: National Renewable Energy Laboratory. pg.34

Table 1: Base Case Building Characteristics Summary

CHARACTERISTIC	HOUSTON BASECASE			
	SOURCES	ASSUMPTIONS		COMMENTS
Building				
Building type		Single family, detached house		
Gross area	NAHB (2003)	2,325 sq. ft. (48.22 ft. x 48.22 ft.)		
Number of floors	NAHB (2003)	1		
Floor to floor height (ft.)	NAHB (2003)	8		
Orientation		South facing		
Construction				
Construction	NAHB (2003)	Light-weight wood frame with 2x4 studs spaced at 16" on center		
Floor	NAHB (2003)	Slab-on-grade floor		
Roof configuration	NAHB (2003)	Unconditioned, vented attic		
Roof absorptance		0.75		Solar Reflectance SR=0.35
Ceiling insulation (hr-sq.ft.-°F/Btu)	2001 IECC, Table 502.2.4(6), (p.83)	R-30		Based on HDD65 and 27% window-to-wall area ratio
Wall absorptance		0.75		Assuming brick facia exterior
Wall insulation (hr-sq.ft.-°F/Btu)	2001 IECC, Table 402.1.1(1), (p.63)	R-13		Based on HDD65
Slab Perimeter Insulation	2001 IECC, Table 502.2.4(6), (p.83)	None		Based on HDD65 and 27% window-to-wall area ratio
Ground reflectance	DOE2.1e User Manual (LBL 1993)	0.24		Assuming grass
U-Factor of glazing (Btu/hr-sq.ft.°F)	2001 IECC, Table 402.1.1(2), (p.63)	0.47		Based on HDD65
Solar Heat Gain Coefficient (SHGC)	2001 IECC, Section 402.1.3.1.4, (p.64)	0.4		0.4 for HDD < 3500, and 0.68 for HDD ≥ 3500
Window area	2001 IECC, Section 402.1.1, (p.63)	18% of conditioned floor area		This amounts to 418.5 sq. ft. window area and 27% window-to-wall area ratio for the assumed base case building configuration
Exterior shading	2001 IECC, Section 402.1.3.1.3, (p.64)	None		
Roof radiant barrier		No		
Roof Radiant barrier emissivity		0.05		
Slope of roof		5:12		Steep slope (5:12 Slope of roof = 23 degree)
Space Conditions				
Space temperature setpoint	2001 IECC, Table 402.1.3.5, (p.64)	68°F Heating, 78°F Cooling, 5°F set-back/ set-up for winter and summer, respectively, for 6 hours per day		
Internal heat gains	2001 IECC, Section 402.1.3.6, (p.65)	0.88 kW (modeled as 0.44 kW for lighting and 0.44 kW for equipment)		
Number of occupants	2001 IECC, Section 402.1.3.6, (p.65)	None		Assuming internal gains include heat gain from occupants
Mechanical Systems		Electric/Gas	All-electric	
HVAC system type		Electric cooling (air conditioner) and natural gas heating (gas fired furmace)	Electric cooling and heating (air conditioner with heat pump)	
HVAC system efficiency	NAECA (2006)	SEER 13 AC, 0.78 AFUE furnace	SEER 13 AC, 7.7 HSPF heat pump	DOE is trying to raise the min AFUE to 80% for "non-weatherized" gas furnaces installed indoors.
Cooling capacity (Btu/hr)		62000		500 sq. ft./ton
Heating capacity (Btu/hr)		62000		1.0 x cooling capacity
DHW system type	Tank size from ASHRAE HVAC Systems and Equipment Handbook	40-gallon tanktype gas water heater	50-gallon tanktype electric water heater (without a pilot light)	
DHW heater energy factor	2001 IECC, Table 504.2, (p.91)	0.54	0.86	(a) 0.62-0.0019V, (b) 0.93-0.00132V, Where V=storage volume (gal.)
Duct location	NAHB (2003)	Unconditioned, vented attic		20-30%
Duct leakage (%)	Parker et al. (1993)	20% (supply) and 10% (return)		
Duct insulation (hr-sq.ft.-°F/Btu)	2001 IECC (As per 2001 source tableNo:503.3.3.3)	R-8 (supply) and R-4 (return)		
HVAC duct static pressure	2001IECC	1		
Supply air flow (CFM/ton)	2001 IECC	360		
Infiltration rate (ACH)	2001 IECC	0.462		ACH=normalized leakage (0.57) X weather factor, and weather factor for Houston=0.81

Table 2: Energy Efficiency Measures

	1	Base Case Natural Gas	Base Case Heat Pump	Source
Renewable Power Options	2	PV Array for 6kW	PV Array for 6kW	City of Houston Officials
	3	PV Array for Partial Demand at 4kW	PV Array for Partial Demand at 4kW	City of Houston Officials
	4	PV Array for Partial Demand at 2kW	PV Array for Partial Demand at 2kW	City of Houston Officials
HVAC Options	5	Manual J: Increased Sqft/ton	Manual J: Increased Sqft/ton	City of Houston Officials
	6	Decreased Supply Airflow	Decreased Supply Airflow	City of Houston Officials
	7	Increased Supply Airflow	Increased Supply Airflow	City of Houston Officials
	8	Decreased Duct Static Pressure	Decreased Duct Static Pressure	City of Houston Officials
	9	Decreased Duct Leakage	Decreased Duct Leakage	City of Houston Officials
	10	Mechanical Systems within Conditioned Spaces	Mechanical Systems within Conditioned Spaces	15% above code analysis
	11	Improved SEER	Improved SEER	15% above code analysis
	12	Improved Furnace Efficiency	Improved Heat Pump	15% above code analysis
Fenestration	13	Decreased SHGC	Decreased SHGC	15% above code analysis
	14	Decreased SHGC & U Value	Decreased SHGC & U Value	15% above code analysis
	15	Window Shading	Window Shading	15% above code analysis
	16	Window Shading and Redistribution	Window Shading and Redistribution	15% above code analysis
Envelope	17	Radiant Barrier	Radiant Barrier	City of Houston Officials
	18	Clay Tiles with a Reflectance of >.40	Clay Tiles with a Reflectance of >.40	City of Houston Officials
	19	Other Roofs with a Reflectance of >.50	Other Roofs with a Reflectance of >.50	City of Houston Officials
	20	Decreased Infiltration	Decreased Infiltration	City of Houston Officials
	21	Increased Infiltration	Increased Infiltration	City of Houston Officials
	22	Low Slope Roof with Increased Reflectance	Low Slope Roof with Increased Reflectance	City of Houston Officials
	23	Low Slope Roof	Low Slope Roof	City of Houston Officials
Lighting Options	24	25% Energy Star CFL Indoor Lamps	25% Energy Star CFL Indoor Lamps	City of Houston Officials
	25	50% Energy Star CFL Indoor Lamps	50% Energy Star CFL Indoor Lamps	City of Houston Officials
	26	Incandescent w occ	Incandescent w/occ	City of Houston Officials
	27	CFL w/o occ	CFLw/o occ	City of Houston Officials
	28	CFL w/ occ	CFL w/occ	City of Houston Officials
DHW Measures	29	Tankless Gas Water Heater	Tankless Gas Water Heater	15% above code analysis
	30	Removal of Pilot Light	NA	15% above code analysis
	31	Solar DHW System	Solar DHW System	15% above code analysis

Table 3: Solar DHW System Characteristics

Number of collector panels	2
Collector panel area	32 sq. ft.
Collector slope	30 deg.
Collector azimuth (South=0)	0 deg.
Number of glazings	1
Collector flow rate/area	11 lb/hr-sq. ft.
Water set temperature	120 deg. F
Daily hot water usage	70 gal.

Table 4: Simulation Input for Base-Case House with Natural Gas Heating

	EEM #	Energy Efficiency Measure	Cooling System Sizing (ft2/ton)	Supply Air Flow (CFM/ton)	Supply Fan Static Pressure	Supply Duct Leakage (%)	Return Duct Leakage (%)	Duct in Conditioned Space	Improved SEER	Improved AFUE	Improved HSPF	SHGC	U-Value	Shading	Shading	Shading	Shading	WWR% for Front Side Wall	WWR% area for Back Side Wall	WWR% for Right Side Wall	WWR% for Left Side Wall	Radiant Barrier	Roof Abs	Infiltration Rate (ACH/hr)	Pitch of Roof (degree)	Lighting (kW)	Energy Factor
	1	Base case Natural Gas w/ setback	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
Renewable Power Options	2	PV Array for 6kW	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	3	PV Array for Partial Demand at 4kW	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	4	PV Array for Partial Demand at 2kW	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
HVAC Options	5	Manual J: Increased Sqft/ton	**650**	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	6	Decreased Supply Airflow	500	**250**	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	7	Increased Supply Airflow	500	**450**	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	8	Decreased Duct Static Pressure	500	360	**0.5**	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	9	Decreased Duct Leakage	500	360	1.0	**6.70%**	**3.30%**	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	10	Mechanical Systems within Conditioned	500	360	1.0	**0%**	**0%**	**ROOM**	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	11	Improved SEER	500	360	1.0	20%	10%	ATTIC	**15**	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	12	Improved Furnace Efficiency	500	360	1.0	20%	10%	ATTIC	13	**0.93**	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
Fenestration	13	Decreased SHGC	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	**0.3**	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	14	Decreased SHGC & U Value	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	**0.3**	**0.35**	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	15	Window Shading	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	**2**	**2**	**2**	**2**	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	16	Window Shading and Redistribution	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	**2**	**2**	**2**	**2**	**48.82**	**27.12**	**16.27**	**16.27**	N	0.75	0.462	23	0.44	0.54
Envelope	17	Radiant Barrier	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	**Y**	0.75	0.462	23	0.44	0.54
	18	Clay Tiles with a Reflectance of >.40	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	**0.55**	0.462	23	0.44	0.54
	19	Other Roofs with a Reflectance of >.50	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	**0.4**	0.462	23	0.44	0.54
	20	Decreased Infiltration	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.35**	23	0.44	0.54
	21	Increased Infiltration	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.65**	23	0.44	0.54
	22	Low Slope Roof with Increased Reflectance	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	**0.3**	0.462	**9.5**	0.44	0.54
	23	Low Slope Roof	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	**9.5**	0.44	0.54
Lighting Options	24	25% Energy Star CFL Indoor Lamps	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	**0.36**	0.54
	25	50% Energy Star CFL Indoor Lamps	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	**0.28**	0.54
	26	Incandescent w occ	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	27	CFL w/o occ	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	28	CFL w occ	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
DHW Measures	29	Tankless Gas Water Heater	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	**0.748**
	30	Removal of Pilot Light	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	**0.57**
	31	Solar DHW System	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54

Table 5: Simulation Results for the Base-Case with Natural Gas Heating (w/ setback), Houston, TX

	EEM #	Energy Efficiency Measure	Total Energy Consumed (MMBtu)	Outdoor Lighting Load	Cooling Load (MMBtu)	Heating Load (MMBtu)	Others (MMBtu)	Fans &Pumps (MMBtu)	DHW (MMBtu)	Diff. %
	1	Base case Natural Gas w/ setback	81.10	0.90	15.80	12.60	26.40	4.90	20.50	0.00%
Renewable Power Options	2	PV Array for 6kW	52.89	0.90	15.80	12.60	26.40	4.90	20.50	34.79%
	3	PV Array for Partial Demand at 4kW	62.29	0.90	15.80	12.60	26.40	4.90	20.50	23.19%
	4	PV Array for Partial Demand at 2kW	71.69	0.90	15.80	12.60	26.40	4.90	20.50	11.60%
HVAC Options	5	Manual J: Increased Sqft/ton	80.60	0.90	15.50	12.40	26.40	4.90	20.50	0.62%
	6	Decreased Supply Airflow	78.70	0.90	14.40	12.20	26.40	4.30	20.50	2.96%
	7	Increased Supply Airflow	84.20	0.90	16.90	13.00	26.40	6.50	20.50	-3.82%
	8	Decreased Duct Static Pressure	78.50	0.90	15.00	13.20	26.40	2.50	20.50	3.21%
	9	Decreased Duct Leakage	75.00	0.90	12.40	9.90	26.40	4.90	20.50	7.52%
	10	Mechanical Systems within Conditioned Spaces	72.00	0.90	10.90	8.40	26.40	4.90	20.50	11.22%
	11	Improved SEER	77.70	0.90	13.30	12.90	26.40	3.70	20.50	4.19%
	12	Improved Furnace Efficiency	79.00	0.90	15.80	10.50	26.40	4.90	20.50	2.59%
Fenestration	13	Decreased SHGC	80.40	0.90	13.70	14.50	26.40	4.40	20.50	0.86%
	14	Decreased SHGC & U Value	77.90	0.90	14.00	11.70	26.40	4.40	20.50	3.95%
	15	Window Shading	79.80	0.90	13.90	13.70	26.40	4.40	20.50	1.60%
	16	Window Shading and Redistribution	78.20	0.90	13.40	12.70	26.40	4.30	20.50	3.58%
Envelope	17	Radiant Barrier	80.20	0.90	15.10	12.50	26.40	4.80	20.50	1.11%
	18	Clay Tiles with a Reflectance of >.40	80.90	0.90	15.50	12.70	26.40	4.90	20.50	0.25%
	19	Other Roofs with a Reflectance of >.50	80.60	0.90	15.30	12.70	26.40	4.80	20.50	0.62%
	20	Decreased Infiltration	78.00	0.90	15.20	10.40	26.40	4.60	20.50	3.82%
	21	Increased Infiltration	86.40	0.90	16.60	16.60	26.40	5.40	20.50	-6.54%
	22	Low Slope Roof with Increased Reflectance	80.60	0.90	15.20	12.80	26.40	4.80	20.50	0.62%
	23	Low Slope Roof	81.70	0.90	16.40	12.50	26.40	5.00	20.50	-0.74%
Lighting Options	24	25% Energy Star CFL Indoor Lamps	78.60	0.90	15.10	13.30	24.00	4.80	20.50	3.08%
	25	50% Energy Star CFL Indoor Lamps	76.20	0.90	14.50	14.00	21.60	4.70	20.50	6.04%
	26	Incandescent w occ	80.24	0.04	15.80	12.60	26.40	4.90	20.50	1.06%
	27	CFL w/o occ	80.44	0.24	15.80	12.60	26.40	4.90	20.50	0.81%
	28	CFL w occ	80.01	0.01	15.80	12.80	26.40	4.50	20.50	1.34%
DHW Measures	29	Tankless Gas Water Heater	75.40	0.90	15.80	12.60	26.40	4.90	14.80	7.03%
	30	Removal of Pilot Light	80.00	0.90	15.80	12.60	26.40	4.90	19.40	1.36%
	31	Solar DHW System	65.01	0.90	15.80	12.60	26.40	6.37	2.94	19.84%

Table 6: Grouping of Results for the Base-Case with Natural Gas Heating (w/ setback), Houston, TX

Range	EEM #	Individual Measures	Percentage Energy Savings above Basecase (%)	Estimated Cost ($)	Type of Cost
Above 15%	3	PV Array for Partial Demand at 4kW	23.2%	$29,000	New System
	2	PV Array for 6kW	34.8%	$41,000	New System
	31	Solar DHW System	19.8%	$2,900 - $5,200	New System
10-15%	10	Mechanical Systems within Conditioned Spaces	11.2%	$1,000 - $7,000	Marginal
	4	PV Array for Partial Demand at 2kW	11.6%	$17,000	New System
5-10%	25	50% Energy Star CFL Indoor Lamps	6.0%	$45 - $100	Marginal
	29	Tankless Gas Water Heater	7.0%	$1,000 - $3,500	Marginal
	9	Decreased Duct Leakage	7.5%	$200 - $450	New System
2-5%	12	Improved Furnace Efficiency	2.6%	$600 - $1,500	Marginal
	16	Window Shading and Redistribution	3.6%	$3,100 - $3,500	New System
	24	25% Energy Star CFL Indoor Lamps	3.1%	$25 - $50	Marginal
	8	Decreased Duct Static Pressure	3.2%	$0 - $250	Marginal
	20	Decreased Infiltration	3.8%	$350 - $1,500	Marginal
	14	Decreased SHGC & U Value	3.9%	$800 - $1,100	Marginal
	11	Improved SEER from 13 to 15	4.2%	$900 - $2,500	Marginal

Table 7: Grouping of the Measures for a Base-Case House with Natural Gas Heating and House with Heat Pump Heating

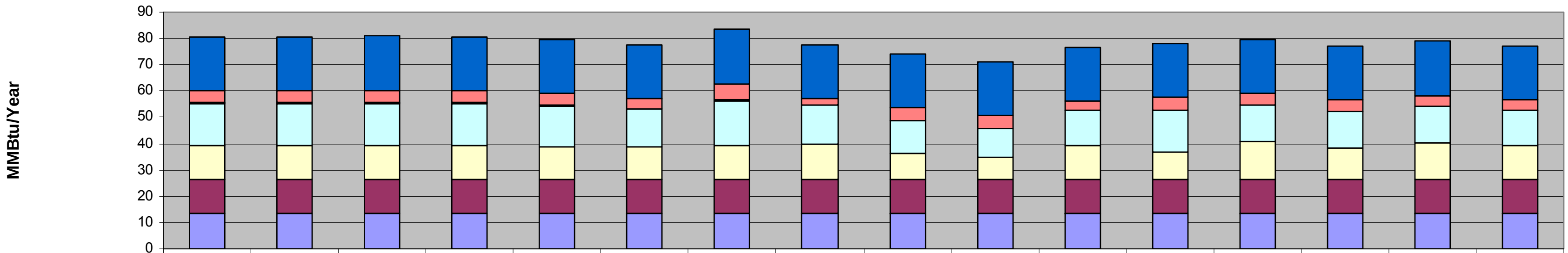
Groups	Base Case with Natural Gas Heating		Base Case with Heat Pump Heating	
	EEM #	Measures	EEM #	Measures
Group 1	31	Solar DHW System	3	PV Array for Partial Demand at 4kW
Group 2	2	PV Array for 6kW	2	PV Array for 6kW
Group 3	3	PV Array for Partial Demand at 4kW	4	PV Array for Partial Demand at 2kW
			20	Decreased Infiltration
Group 4	10	Mechanical Systems within Conditioned Spaces	31	Solar DHW System
	25	50% Energy Star Indoor Lamps	20	Decreased Infiltration
Group 5	4	PV Array for Partial Demand at 2kW	25	50% Energy Star CFL Indoor Lamps
	9	Decreased Duct Leakage	9	Decreased Duct Leakage
Group 6	29	Tankless Gas Water Heater	10	Mechanical Systems within Conditioned Spaces
	25	50% Energy Star CFL Indoor Lamps	11	Improved SEER from 13 to 15
	20	Decreased Infiltration	20	Decreased Infiltration
Group 7	9	Decreased Duct Leakage	25	50% Energy Star CFL Indoor Lamps
	25	50% Energy Star CFL Indoor Lamps	11	Improved SEER from 13 to 15
	11	Improved SEER from 13 to 15	14	Decreased SHGC & U Value
Group 8	9	Decreased Duct Leakage	9	Decreased Duct Leakage
	11	Improved SEER from 13 to 15	24	25% Energy Star CFL Indoor Lamps
	14	Decreased SHGC & U Value	11	Improved SEER from 13 to 15
	20	Decreased Infiltration	15	Window Shading
Group 9	9	Decreased Duct Leakage	9	Decreased Duct Leakage
	14	Decreased SHGC & U Value	14	Decreased SHGC & U Value
	8	Decreased Duct Static Pressure	11	Improved SEER from 13 to 15
	16	Window Shading and Redistribution	20	Decreased Infiltration
Group 10	9	Decreased Duct Leakage	24	25% Energy Star CFL Indoor Lamps
	11	Improved SEER from 13 to 15	8	Decreased Duct Static Pressure
	20	Decreased Infiltration	16	Window Shading and Redistribution
	12	Improved Furnace Efficiency	14	Decreased SHGC & U Value

Table 8: Simulation Inputs for the Grouped Measures for the Base-Case House with Natural Gas Heating

Group #	Energy Efficiency Measure	Cooling System Sizing (ft2/ton)	Supply Air Flow (CFM/ton)	Supply Fan Static Pressure	Supply Duct Leakage (%)	Return Duct Leakage (%)	Duct in Conditioned Space	Improved SEER	Improved AFUE	Improved HSPF	SHGC	U-Value	Shading	Shading	Shading	Shading	WWR% for front side wall	WWR% area for backside wall	WWR% for right side wall	WWR% for left side wall	Radiant Barrier	Roof Abs	Infiltration Rate (ACH/hr)	Pitch of Roof (degree)	Lighting (kW)	Energy Factor
	Base case Natural Gas w/ setback	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
1	Group 1 - Solar DHW System	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
2	Group 2 -PV Array for 6kW	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
3	Group 3 -PV Array for 4kW	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
4	Group 4 -Mechanical Systems within Conditioned Space -50% Energy Star Lighting	500	360	1.0	**0%**	**0%**	**ROOM**	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	**0.28**	0.54
5	Group 5 -PV Array for Partial Demand at 2kW -Decreased Duct Leakage	500	360	1.0	**6.70%**	**3.30%**	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
6	Group 6 -50% Energy Star CFL Indoor Lamps - Tankless Water Heater - Decreased Infiltration	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.35**	23	**0.28**	**0.748**
7	Group 7 -50% Energy Star Indoor Lamps -Decreased Duct Leakage -Improved SEER from 13 to 15	500	360	1.0	**6.70%**	**3.30%**	ATTIC	**15**	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	**0.28**	0.54
8	Group 8 - Decreased Duct Leakage - Improved SEER from 13 to 15 - Decreased SHGC and U - Decreased Infiltration	500	360	1.0	**6.70%**	**3.30%**	ATTIC	**15**	0.78	7.70	**0.3**	**0.35**	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.35**	23	0.44	0.54
9	Group 9 -Decreased Duct Leakage -Decreased Static Pressure -Decreased SHGC & U-Value -Window Shading and Redistribution	500	360	**0.5**	**6.70%**	**3.30%**	ATTIC	13	0.78	7.70	**0.3**	**0.35**	**2**	**2**	**2**	**2**	**48.82**	**27.12**	**16.27**	**16.27**	N	0.75	0.462	23	0.44	0.54
10	Group 10 -Improved Furnace Efficiency -Decreased Infiltration -Decreased Duct Leakage -Improved SEER from 13 to 15	500	360	1.0	**6.70%**	**3.30%**	ATTIC	**15**	**0.93**	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.35**	23	0.44	0.54

Table 9: Combined Energy Savings of Grouped Measures for a Base-Case House with Natural Gas Heating (w/ setback), Houston, TX

Groups	EEM #	Measures	Combined Energy Savings (%)	Electricity Savings (kWh/yr)	Combined Gas Savings (CCF/yr)
Group 1	**31**	Solar DHW System	20.4%	-313	172
Group 2	**2**	PV Array for 6kW	35.3%	8,385	2
Group 3	**3**	PV Array for Partial Demand at 4kW	23.8%	5,629	2
Group 4	**10**	Mechanical Systems within Conditioned Spaces	17.9%	3,283	33
	25	50% Energy Star Indoor Lamps			
Group 5	**4**	PV Array for Partial Demand at 2kW	19.7%	3,870	28
	9	Decreased Duct Leakage			
Group 6	**29**	Tankless Gas Water Heater	17.6%	2,227	66
	25	50% Energy Star CFL Indoor Lamps			
	20	Decreased Infiltration			
Group 7	**9**	Decreased Duct Leakage	17.4%	3,722	15
	25	50% Energy Star CFL Indoor Lamps			
	11	Improved SEER from 13 to 15			
Group 8	**9**	Decreased Duct Leakage	17.5%	2,667	50
	11	Improved SEER from 13 to 15			
	14	Decreased SHGC & U Value			
	20	Decreased Infiltration			
Group 9	**9**	Decreased Duct Leakage	16.0%	2,960	29
	14	Decreased SHGC & U Value			
	8	Decreased Duct Static Pressure			
	16	Window Shading and Redistribution			
Group 10	**9**	Decreased Duct Leakage	16.3%	2,198	56
	11	Improved SEER from 13 to 15			
	20	Decreased Infiltration			
	12	Improved Furnace Efficiency			



	BASE CASE NATURAL GAS	PV Array for 6kW	PV Array for Partial Demand at	PV Array for Partial Demand at	Manual J: Oversized Cooling	Decreased Supply Airflow	Increased Supply Airflow	Decreased Duct Static Pressure	Decreased Duct Leakgae	Mechanical Systems w ithin	Improved SEER	Improved Furnace Efficiency	Decreased SHGC	Decreased SHGC & U value	Window Shading	Window Shading and redistribution
DOMHOT WATER	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5
VENT FANS	4.8	4.8	4.8	4.8	4.7	4.1	6.3	2.3	4.7	4.7	3.5	4.7	4.2	4.2	4.2	4.1
PUMPS & MISC	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SPACE COOLING	16.1	16.1	16.1	16.1	15.5	14.4	16.9	15	12.4	10.9	13.3	15.8	13.7	14	13.9	13.4
SPACE HEATING	12.8	12.8	12.9	12.8	12.4	12.2	13	13.2	9.9	8.4	12.9	10.5	14.5	11.7	13.7	12.7
MISC EQUIPMT	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
AREA LIGHTING	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2

Figure 1: Energy Use of various EEMs for Base-Case House with Natural Gas Heating (w setback), Houston, TX